

Triac Power Controls for Three-Phase Systems

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The growing demand for solid-state switching of ac power in heating controls and other industrial applications has resulted in the increasing use of triac circuits in the control of three-phase power. This Note explains a basic approach to the design of triac control circuits for use in the switching of three-phase power. The basic design rules employed in this approach are outlined, an integrated-circuit zero-voltage switch specifically intended for use in triac triggering is briefly described, and the necessity for and methods of isolation of the dc logic circuitry in power controls for three-phase systems are pointed out. Recommended configurations are then shown for power-control circuits intended for use with both inductive and resistive balanced three-phase loads, and the specific design requirements for each type of loading condition are discussed. (Unbalanced three-phase systems, which have different design requirements, are not covered in this Note.)

Basic Design Rules

In the power-control circuits described in this Note, the RCA-CA3059 integrated-circuit zero-voltage switch is used as the trigger circuit for the power triacs.* The following conditions are also imposed in the design of the triac control circuits:

1. The load should be connected in a three-wire configuration with the triacs placed external to the load; either delta or wye arrangements may be used. Four-wire loads in wye configurations can be handled as three independent single-phase systems. Delta configurations in which a triac is connected within each phase rather than in the incoming lines can also be handled as three independent single-phase systems.

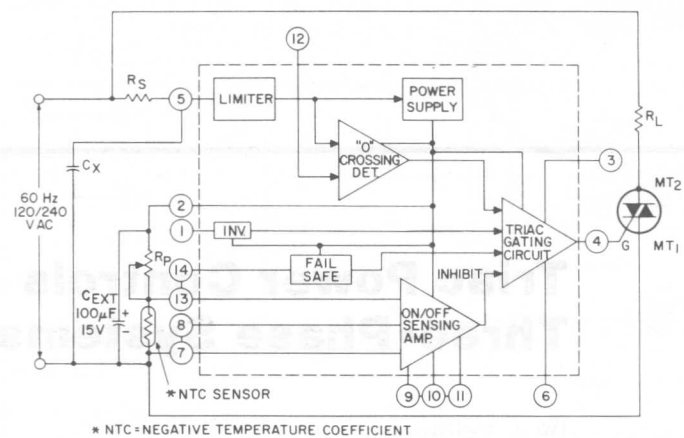
*In addition to the CA3059, the RCA-CA3058 and -CA3079 integrated-circuit zero-voltage switches may also be used for triac triggering in the power-control circuits. All information given on the CA3059 in this Note is, in general, equally applicable to the CA3058 and CA3079.

2. Only one logic command signal is available for the control circuits. This signal must be electrically isolated from the three-phase power system.
3. Three separate triac gating signals are required.
4. For operation with resistive loads, the zero-voltage-switching technique should be used to minimize any radio-frequency interference (RFI) that may be generated.

Integrated-Circuit Zero-Voltage Switch

The RCA-CA3059 integrated-circuit zero-voltage switch is intended primarily as a trigger circuit for the control of thyristors and is particularly suited for use in thyristor temperature-control applications. Fig. 1 shows a functional block diagram of the CA3059 integrated-circuit zero-voltage switch. This multistage circuit employs a diode limiter, a threshold detector, a differential amplifier, and a Darlington output driver to provide the basic switching action. The dc supply voltage for these stages is supplied by an internal zener-diode-regulated power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. The trigger pulse developed by this circuit can be applied directly to the gate of an SCR or a triac. A built-in fail-safe circuit inhibits the application of these pulses to the thyristor gate circuit in the event that the external sensor for the integrated-circuit switch should be inadvertently opened or shorted. The CA3059 may be employed as either an on-off type of controller or a proportional controller, depending upon the degree of temperature regulation required.

Fig. 2 shows the schematic diagram for the CA3059 integrated circuit. Any triac that is driven directly from the output terminal of this circuit should be characterized for operation in the I(+) or III(+) triggering modes, i.e., with positive gate current (current flows into the gate for both polarities of the applied ac voltage). The circuit operates directly from a 50-, 60-, or 400-Hz ac line voltage of 120 to 277 volts.



AC Input Voltage (50/60 or 400 Hz) V AC	Input Series Resistor (R _S) k Ω	Dissipation Rating for R _S W
24	2	0.5
120	10	2
208/230	20	4
277	25	5

Fig. 1—Functional block diagram of the CA3059 integrated-circuit zero-voltage switch.

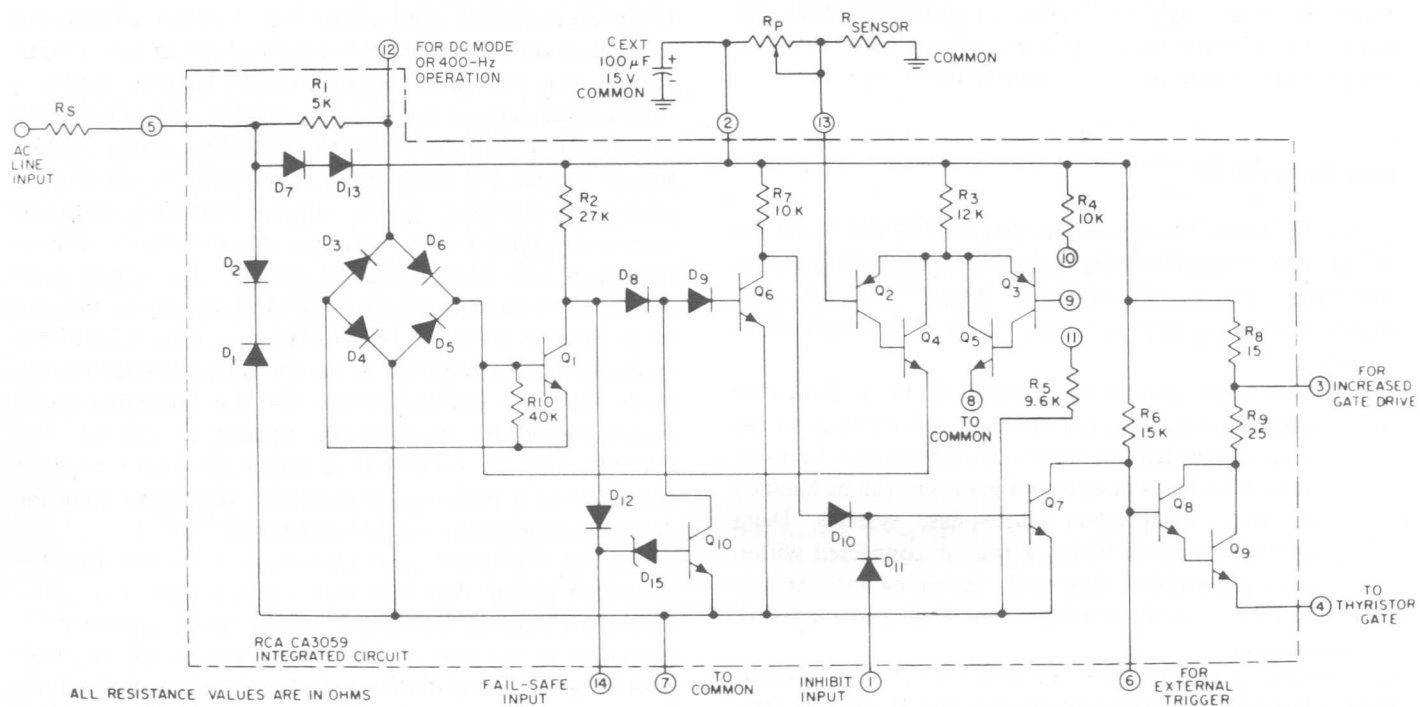


Fig. 2—Circuit diagram for the CA3059 zero-voltage switch.

The diodes D1 and D2 in the CA3059 form a limiter stage that clips the incoming ac line voltage to approximately plus and minus 8 volts. This signal is then applied to the zero-voltage-crossing detector (diodes D3 through D6 and transistor Q1), which generates an output pulse during each passage of the line voltage through zero. The limiter output is also applied to the rectifying diodes D7 and D13 and the external capacitor CEXT that comprise the dc power supply. The power supply provides approximately 6 volts (at terminal 2) as the dc supply to the other stages of the CA3059. The on/off sensing amplifier (transistors Q2 through Q5) is basically a differential comparator. The triac gating circuit contains a driver (transistors Q8 and Q9) for direct triac triggering. The gating circuit is enabled when all the inputs are at a high voltage, i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be "high", the external voltage to terminal 1 must be a logical "1", and the output of the fail-safe circuit must be "high".

Fig. 3 shows the position and width of the pulses supplied to the gate of a thyristor with respect to the incoming ac line voltage. The CA3059 can supply sufficient gate voltage and current to trigger most RCA thyristors at ambient temperatures of 25°C. However, under worst-case conditions (i.e., at low ambient-temperature extremes and maximum trigger requirements), selection of the higher-current thyristors may be necessary for particular applications. (The RCA technical bulletin File No. 406 lists triacs designed for use with the integrated-circuit zero-voltage switch as the triggering circuit. Detailed information on the operating characteristics and capabilities of this integrated circuit are given in RCA technical bulletin File No. 490, RCA application notes ICAN-6158 and ICAN-6268, and the RCA *Linear Integrated Circuits Manual*, IC-42.)

As shown in Fig. 1, when terminal 13 is connected to terminal 14, the fail-safe circuit of the CA3059 is operable. If the sensor should then be accidentally opened or shorted, power is removed from the load (i.e., the triac is turned off). The internal fail-safe circuit functions properly, however, only when the ratio of the sensor impedance at 25°C, if a thermistor is the sensor, to the impedance of the potentiometer, R_p , is less than 4 to 1.

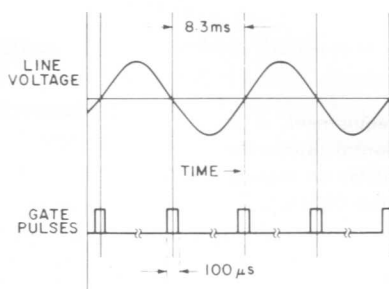


Fig. 3—Timing relationship between the output pulses of the CA3059 and the ac line voltage (pulse duration shown is a typical value for operation from a 120-volt 60-Hz line voltage).

Isolation of DC Logic Circuitry

Isolation of the dc logic circuitry* from the ac line, the triac, and the load circuit is often desirable even in many single-phase power-control applications. In control circuits for polyphase power systems, however, this type of isolation is essential, because the common point of the dc logic circuitry cannot be referenced to a common line in all phases.

In the three-phase circuits described in this Note, photo-optic techniques (i.e., photo-coupled isolators) are used to provide the electrical isolation of the dc logic command signal from the ac circuits and the load. The photo-coupled isolators consist of an infrared light-emitting diode aimed at a silicon photo transistor, coupled in a common package. The light-emitting diode is the input section, and the photo transistor is the output section. The two components provide a voltage isolation typically of 1500 volts. Other isolation techniques, such as pulse transformers, magnetoresistors, or reed relays, can also be used with some circuit modifications.

Resistive Loads

Fig. 4 illustrates the basic phase relationships of a balanced three-phase resistive load, such as may be used in heater applications, in which the application of load power is controlled by zero-voltage switching. The following conditions are inherent in this type of application:

1. The phases are 120 degrees apart; consequently, all three phases cannot be switched on simultaneously at zero voltage.
2. A single phase of a wye configuration type of three-wire system cannot be turned on.
3. Two phases must be turned on for initial starting of the system. These two phases form a single-phase circuit which is out of phase with both of its component phases. The single-phase circuit leads one phase by 30 degrees and lags the other phase by 30 degrees.

These conditions indicate that in order to maintain a system in which no appreciable RFI is generated by the switching action from initial starting through the steady-state operating condition, the system must first be turned on, by zero-voltage switching, as a single-phase circuit and then must revert to synchronous three-phase operation.

Fig. 5 shows a simplified circuit configuration of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating condition, with random starting. In this system, the logic command to turn on the system is given when heat is required, and the command to turn off the system is given when heat is not required. Time proportioning heat control is also possible through the use of logic commands.

*The dc logic circuitry provides the low-level electrical signal that dictates the state of the load. For temperature controls, the dc logic circuitry includes a temperature sensor for feedback. The RCA integrated-circuit zero-voltage switch, when operated in the dc mode with some additional circuitry, can replace the dc logic circuitry for temperature controls.

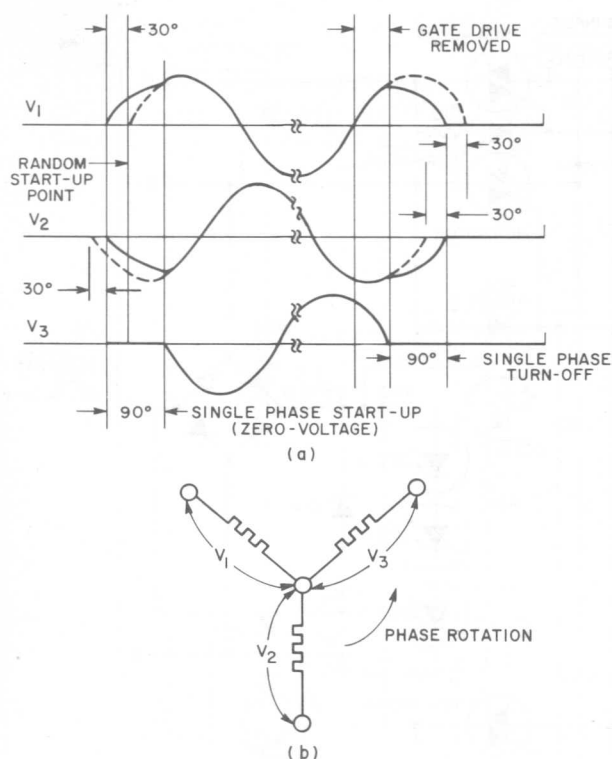


Fig. 4— Voltage phase relationship for a three-phase resistive load when the application of load power is controlled by zero-voltage switching: (a) voltage waveforms, (b) load-circuit orientation of voltages. (The dashed lines indicate the normal relationship of the phases under steady-state conditions. The deviation at start-up and turn-off should be noted.)

The three photo-coupled inputs to the three CA3059 circuits change state simultaneously in response to a "logic command". The CA3059 circuits then provide a positive pulse, approximately 100 microseconds in duration, only at a zero-voltage crossing relative to their particular phase. A balanced three-phase sensing circuit is set up with the three CA3059 circuits each connected to a particular phase on their common side (terminal 7) and referenced at their high side (terminal 5), through the current-limiting resistors R4, R5, and R6, to an established artificial neutral point. This artificial neutral point is electrically equivalent to the inaccessible neutral point of the wye type of three-wire load and, therefore, is used to establish the desired phase relationships. The same artificial neutral point is also used to establish the proper phase relationships for a delta type of three-wire load. Because only one triac is pulsed on at a time, the diodes (D1, D2, and D3) are necessary to trigger the opposite-polarity triac, and, in this way, to assure initial latching-on of the system. The three resistors (R1, R2, and R3) are used for current limiting of the gate drive when the opposite-polarity triac is triggered "on" by the line voltage.

In critical applications that require suppression of all generated RFI, the circuit shown in Fig. 6 may be used. In addition to synchronous steady-state operating conditions, this circuit also incorporates a zero-voltage starting circuit. The start-up condition is zero-voltage synchronized to a single-phase, 2-wire, line-to-line circuit, comprised of phases A and B. The logic command engages the single-phase "start-up" CA3059 and three-phase photo-coupled isolators OCI3, OCI4, OCI5 through the photo-coupled isolators OCI1 and OCI2. The single-phase CA3059, which is synchronized to phases A and B, starts the system at zero voltage. As soon

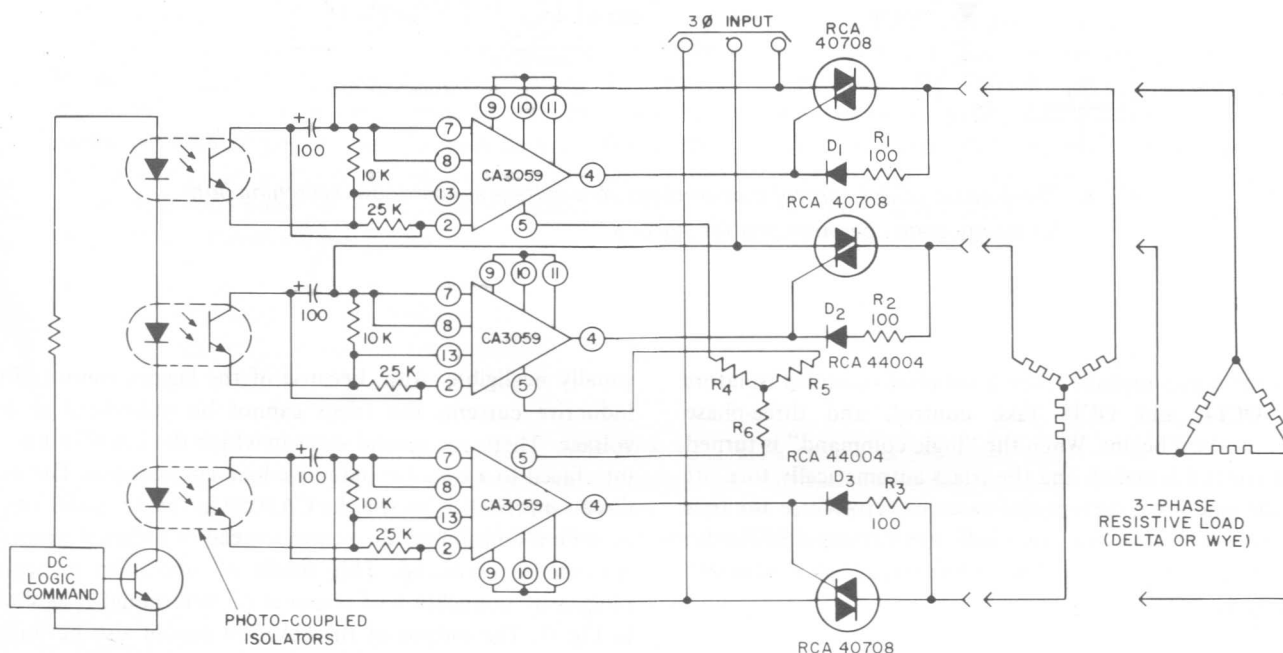


Fig. 5—Simplified diagram of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating conditions.

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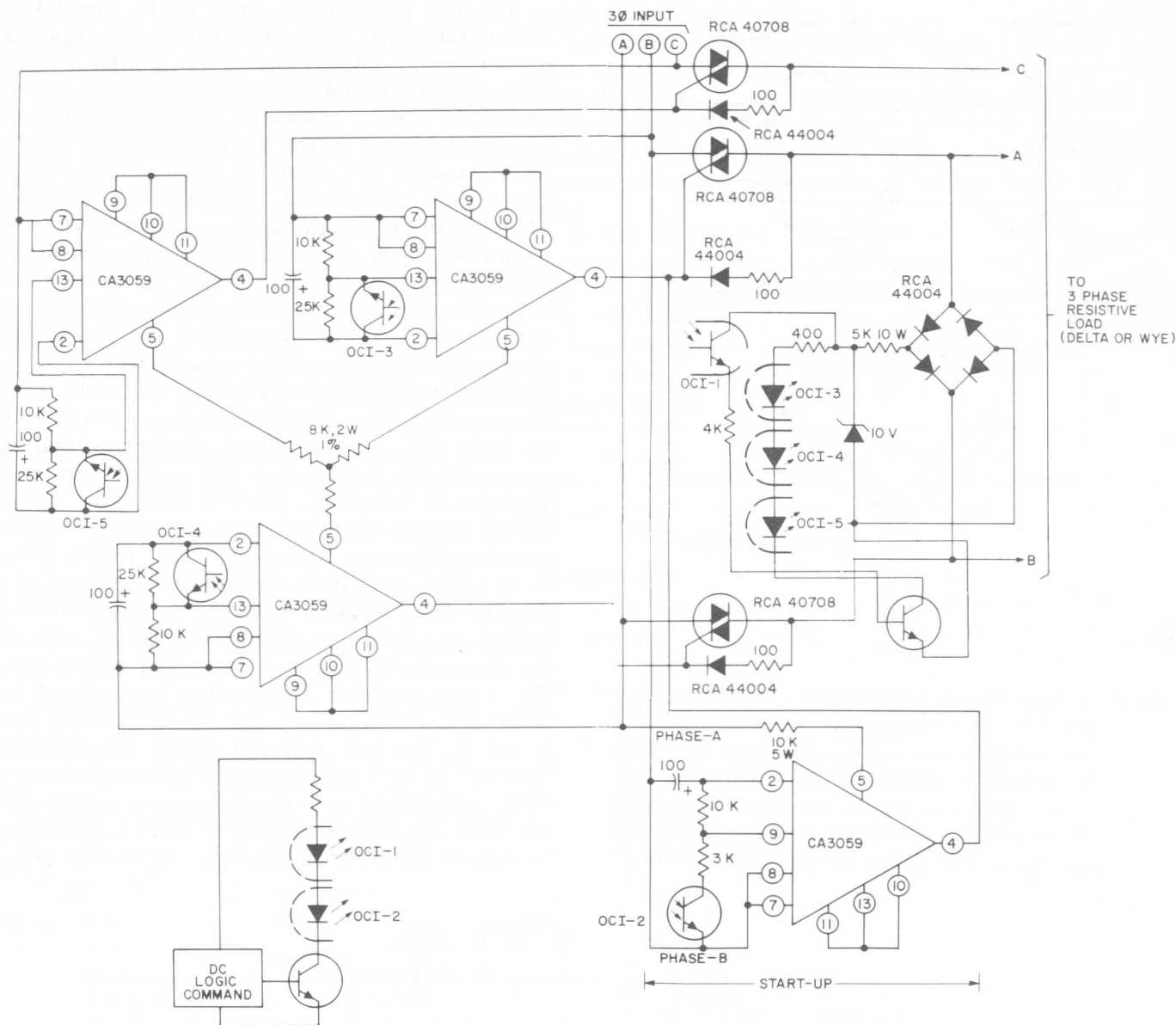


Fig. 6—Three-phase power control that employs zero-voltage synchronous switching both for steady-state operation and for starting.

as start-up is accomplished, the three photo-coupled isolators OCI13, OCI14, and OCI15 take control, and three-phase synchronization begins. When the "logic command" is turned off, all control is ended, and the triacs automatically turn off when the sine-wave current decreases to zero. Once the first phase turns off, the other two will turn off simultaneously, 90° later, as a single-phase line-to-line circuit, as is apparent from Fig. 4.

Inductive Loads

For inductive loads, zero-voltage turn-on is not generally required because the inductive current cannot increase instantaneously; therefore, the amount of RFI generated is

usually negligible. Also, because of the lagging nature of the inductive current, the triacs cannot be pulse-fired at zero voltage. There are several ways in which the CA3059 may be interfaced to a triac for inductive-load applications. The most direct approach is to use the CA3059 in the dc mode, i.e., to provide a continuous dc output instead of pulses at points of zero-voltage crossing. This mode of operation is accomplished by connection of terminal 12 to terminal 7, as shown in Fig. 7. The output of the CA3059 should also be limited to approximately 5 milliamperes in the dc mode by the 750-ohm series resistor. Use of a triac such as the RCA 40692 is recommended for this application. Terminal 3 is connected to terminal 2 to limit the steady-state power

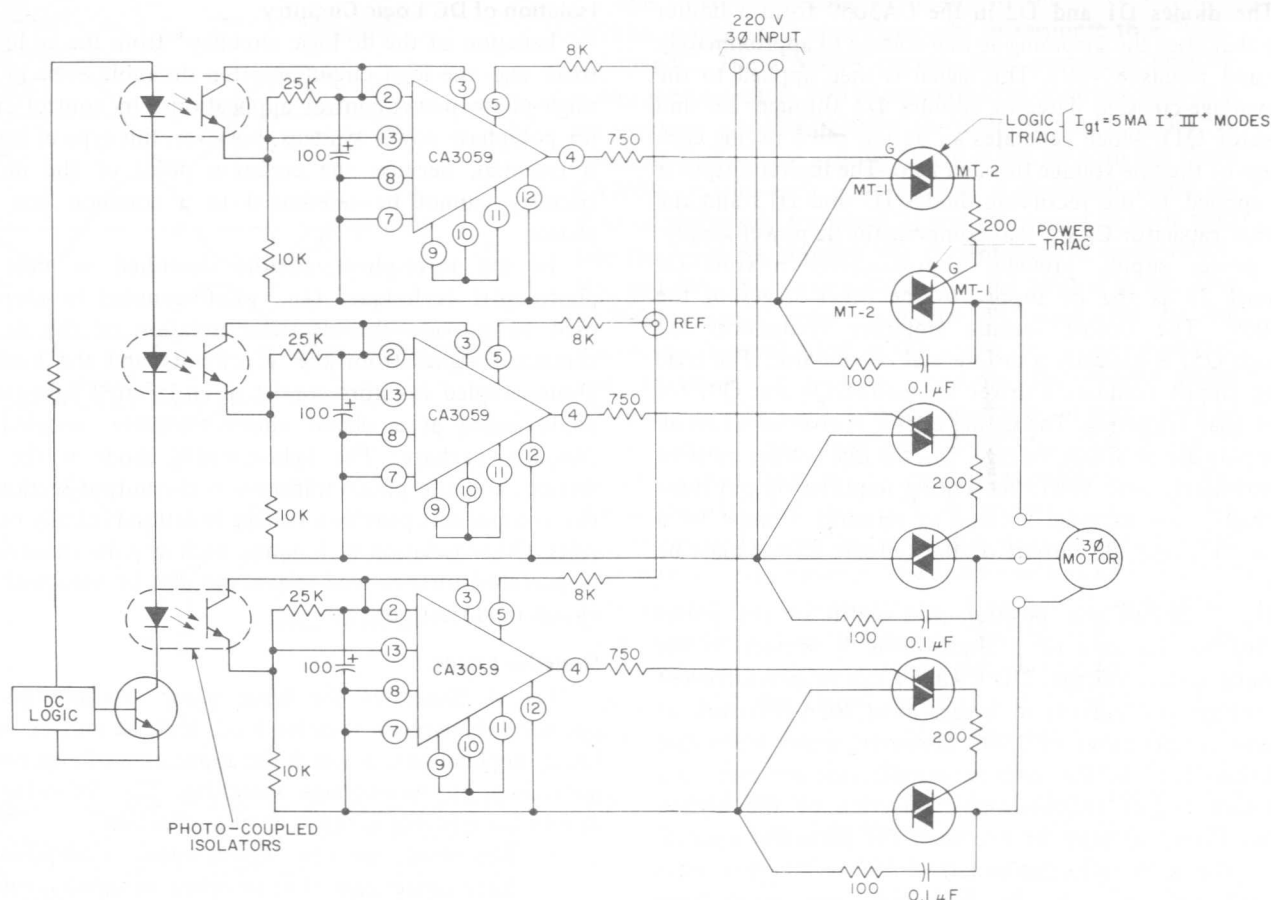


Fig. 7—Triac three-phase control circuit for an inductive load, i.e., three-phase motor.

dissipation within the CA3059. For most three-phase inductive load applications, the current-handling capability of the 40692 triac (2.5 amperes) is not sufficient. Therefore, the 40692 is used as a trigger triac to turn on any other currently available power triac that may be used. The trigger triac is used only to provide trigger pulses to the gate of the power triac (one pulse per half cycle); the power dissipation in this device, therefore, will be minimal.

Simplified circuits using pulse transformers and reed relays will also work quite satisfactorily in this type of application. The RC networks across the three power triacs are used for suppression of the commutating dv/dt when the circuit operates into inductive loads. (A detailed explanation of commutating dv/dt is provided in the basic discussion of thyristors in the *RCA Solid-State Power Circuits Designer's Handbook*, SP-52.)

When incorporating RCA Solid State Devices in equipment, it is recommended that the designer refer to "Operating Considerations for RCA Solid State Devices", Form No. 1CE-402, available on request from RCA Solid State Division, Box 3200, Somerville, N.J. 08876.